Energy Efficient Node Placement Using Genetic Algorithm

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Abstract: Some of the wireless sensor network applications require optimization of communication among sensors so as to serve data in short latency and minimal energy. A Genetic Algorithm based multi-objective methodology is developed for a self-organizing wireless sensor network. Genetic algorithm is used as a technique in the selection of sensor nodes which play special roles in running caching and request forwarding decisions. Design parameters such as network density, connectivity and energy consumption are taken into account for developing the fitness function. The algorithm is implemented in MATLAB using Genetic Algorithm toolbox.

Keywords: Self-organizing, Caching, Fitness function

I Introduction

A wireless sensor network consists of wirelessly interconnected devices (each being able to compute, control and communicate with each other) that can interact with their environment by controlling and sensing "physical" parameters. WSNs have fueled a huge number of applications, such as disaster relief, environment control and biodiversity mapping, machine surveillance, intelligent building, precision agriculture, pervasive health applications, target tracking in battlefields, and so on. A WSN generally consists of a large number of low-cost, low-power, multifunctional, energy constrained sensor nodes with limited computational and communication capabilities. In WSNs sensors may be deployed either randomly or deterministically depending upon the application. The major characteristics of WSN call for optimization. Network lifetime is one of the important parameters to optimize as energy resources in a WSN are limited due to operation on battery. Replacing or recharging of battery in the network may be infeasible. Though the overall function of the network may not be hampered due to failure one or few nodes of the network as neighboring nodes may take over, but for optimum performance the network density must be high enough. Network connectivity which depends upon the communication protocol is another WSN design issue. The above mentioned issues call for simultaneous optimization of more than one nonlinear design criteria. Genetic Algorithm (GA) is one of the most powerful heuristics for solving optimization problems that is based on natural selection. The GA repeatedly modifies a population of individual solutions. At each step, the genetic algorithm selects individuals at random from the current population to be parents and uses them to produce the children for the next generation. Over successive generations, the population "evolves" towards an optimal solution.

Sensor needs to construct responses to quite complex queries whose processing may involve the cooperation with many neighboring sensors and the communication among them is strictly multi hop. The battery lifetime can be extended if the 'amount' of communication is reduced, which in turn can be done by caching useful data for each sensor either in its local store or in the near neighborhood. Additionally, caching can be very effective in reducing the need for network-wide transmissions, thus reducing the

interference and overcoming the variable channel conditions. The cooperative data caching has been proposed as an effective and efficient technique to achieve these goals the The fundamental aspect of using Genetic Algorithm for sensor networks is the identification of the nodes which will implement the aspects of the cooperation concerning the caching decisions.

II Related Work

Caching is a significant technique to improve the performance of wireless networks. Cooperative caching has attracted the attention; several cooperative caching protocols has been introduced [1]-[11], these approaches try to reduce the communication delay by finding nodes which play special role in caching.

Several researches have been carried out in implementing GA in sensor network design [12]-[14], this led to several GA based WSN design. However these approaches fail to incorporate caching technique in to the network. The proposed method helps in finding the nodes which take special roles in caching optimally.

III Network Model

This work assumes a caching application which involves placement of three types of sensors on a two dimensional field for monitoring parameters say CCN, n1 and n2. It is assumed that variation of CCN in the 2D field is much less than n1 and the variation of n2 is much less than n1 in order to monitor the field optimally.

Consider a square field of L x L Euclidian units subdivided into grids separated by a predefined Euclidian distance. The sensing nodes are placed at the intersections of these grids so that the entire area of interest is covered as in Fig. 1

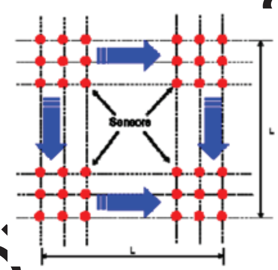

Figure 1. A grid based WSN layout.

The sensing nodes are identical and the nodes are capable of playing one of the three operating roles i.e. Community caching node(CCN) or Normal node with higher transmission range (n1) or Normal node with lower transmission range (n2)provided they are active. The nodes acting as CCN has the highest transmission range when compared to normal node. A simple grouping method is used where in the nodes operating in CCN mode acts as community caching node and are capable to communicate to data center via multi hop communication and groups are formed based on the vicinity of sensors to CCN. It is clear that CCN sensors will consume more energy than other two modes.

IV Methodology

A multi-objective Genetic algorithm to design WSN topologies is being explored. The algorithm optimizes application specific parameters, connectivity parameters and energy parameters by using a single fitness function. This fitness function gives the quality measure of each WSN topology and further optimizes it to best topology. WSN design parameters can be broadly classified into three categories. The first category colligates parameters regarding sensor placement specifically, uniformity and coverage of sensing and measuring points respectively. The second category colligates the connectivity parameters such as number of Caching nodes and the guarantee that no node remains unconnected. The third category colligates the energy related parameters such as the operational energy consumption depending on the types of active sensors. The design optimization is achieved by minimizing constraints such as, operational energy,

number of unconnected sensors and number of overlapping Community caching node ranges. Whereas the parameters such as, field coverage and number of sensors per community caching node are to be maximized. A weighted sum approach has been used to aggregate all these optimization constraints and an objective function is formed as given by the equation (1) this objective function is the basis for forming the “fitness function” for the GA and gives a numerical figure for quality measure of each possible solution of the optimization problem.

$$F = \min(\textstyle\sum_{i=1}^{5} k_i x_i) \qquad (1)$$

Table I Symbols

Objective	**Optimization Parameter**	**Symbols**
x1	Field Coverage	FC
x2	Overlaps Per Caching in charge error	OpCcE
x3	Sensor out of range error	SORE
x4	Sensors per caching in charge	SpCc
x5	Network Energy	NE

A. The Optimization Parameters are found as follows

1) Application-specific parameter*:* The effectiveness of a distributed WSN highly depends upon the sensor deployment scheme. It is highly desirable to deploy the sensing nodes such that maximum field coverage and high quality communication is achieved. Here, a field coverage parameter is defined as under:

$$\mathrm{FC} = \frac{(\mathrm{Nccn} + \mathrm{Nn}_1 + \mathrm{Nn}_2) - (\mathrm{Nor} + \mathrm{Ninact})}{\mathrm{Ntotal}} \qquad (2)$$

Where,
Nccn: - number of CCN Sensors (community caching nodes)
Nn1:- number of normal node Sensors (HSR)
Nn2:- number of normal node Sensors (LSR)
Ninact: - Number of inactive sensors
Nor: - number of Out of Range Sensors
Ntotal: - total number of sensing points

2) Connectivity parameters**:** Perpetual network connectivity is a crucial issue in WSNs. Following parameters are taken into account for reliable network connectivity

a) Sensors-per- Community caching node (SpCc) parameter which ascertains that each community caching node does not earmark sensors more than its traffic handling, data management and the sensor physical communication capabilities

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$$\mathrm{SpCc} = \frac{(\mathrm{Nn_1}+\mathrm{Nn_2})-(\mathrm{Nor})}{\mathrm{Nccn}} \qquad (3)$$

b) Sensors-Out-of-Range Error (SORE) parameter to ascertain that each sensor gets included in a group. This of course depends on the communication range of the sensor nodes. It is assumed that Y mode sensors cover a circular area with radius equal to 2 length units, while Z mode sensors cover a circular area with radius equal to 1 length units. SORE is given by

$$\mathrm{SORE} = \frac{\mathrm{Nor}}{\mathrm{Ntotal}-\mathrm{Ninact}} \qquad (4)$$

c) Overlaps-per-community caching node- error (OpCcE)parameter which ensures that the caching-in-charges are so distributed or chosen such that there is a minimum overlapping of community caching node ranges, i.e to ensure that a sensor remains loyal to one cache-in-charge only. OpCiE is given by

$$\mathrm{OpCcE} = \frac{\text{Number of overlaps}}{\mathrm{Nccn}} \qquad (5)$$

3) Energy-related parameter: Energy consumption is a crucial issue affecting the overall performance of a WSN in terms of reliability and life time. An optimization parameter defined as Network Energy (NE) is taken into consideration here, which is a numerical measure of energy consumption depending on a network design. It basically depends on the operational roles of the sensing nodes, sensors operating Community caching nodes (CCN) will obviously consume the highest energy as they require high communication power for perform caching and request forwarding decisions, the nodes acting as normal nodes consume less power than CCN nodes. Here, it is assumed that a node in CCN nodes consumes 4 times power than in Normal node Hence the NE consumption parameter is given by

$$NE = \frac{4*Nccn+2*Nn_1+Nn_2}{Ntotal} \qquad (6)$$

B.WSN Representation:

As described in previous section a square field of L x L length units is considered which is subdivided into grids of unit lengths. The nodes are assumed to be placed on intersections of these grids. An individual in GA population is represented by a bit string and is used to encode sensor nodes in a row by row fashion

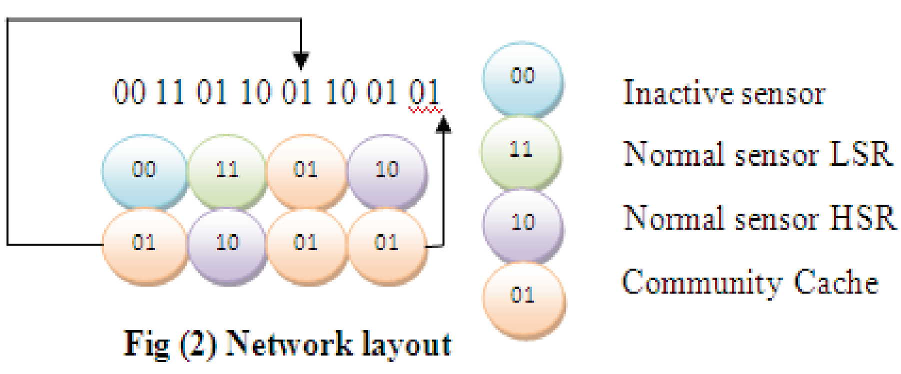

Figure.2 Network Layout

The length of this bit string is L^2. In this bit string the sequence of bits decides the type of node 0 being Normal, 1 being Community caching node. Thus if the value of L is 10 then the length of the bit string would be 100.

C. Fitness function, Genetic operators and Selection Mechanism

The Fitness function must include and correctly represent all important design parameters.Fitness function is formulated as

$$F= -\alpha1\ FC+ \alpha2\ SpCc+\alpha3\ NE+ \alpha4OpCcE- \alpha5SORE \qquad (7)$$

It may be noted that the coefficient α1 and α4 has negative sign this is because the GA toolbox of MATLAB optimizes the problem by minimizing the fitness value and in order to maximize the parameters corresponding to these particular coefficients they have to be multiplied by a negative sign. In fitness function significance of each parameter is designed by setting weighting coefficient α_i where i=1,2,.... The values of these coefficients were determined based on design requirements and experimentation.

Table II Optimized Values of Weighing Coefficient

Objective	Optimization Parameter	Coefficient	Optimized value
x1	FC	α1	4
x2	OPCcE	α4	0.5
x3	SORE	α5	10
x4	SPCc	α2	1
x5	NE	α3	1

Two points cross over with probability of 0.8 was used. The mutation type that was used was Nonlinear mutation with probability of 0.1.selection mechanism used here was the roulette wheel selection scheme. The probability of selecting some individual to become a parent for the production of the next generation was proportional to its fitness value. In addition, in order to assure that the best individual of each generation was not destroyed by the crossover and mutation operators during the evolution process, “elitism” was included in the algorithm, meaning that the current best individual at each generation of the algorithm always survived to the next generation.

V Experimentation

GAs involves exploration and tuning of a number of problem specific parameters for optimizing its performance, namely the population size, crossover and mutation methodologies. Firstly, a number of experiments were conducted to determine appropriate population size, size ranging from 100 to 1000 individuals. However, the best performance, by means of maximizing the corresponding fitness function, was achieved with a population size of 300 individuals. The quality of the randomly generated initial population plays an important role in the final performance. Thus, several runs were tested with different random initial populations. Average results over the several runs as well as the best solutions achieved by each set of parameters were used to draw conclusions. The performance of the algorithm in designing initial optimal WSN topologies was obtained.

Thus, the algorithm was applied in a field of 10 x 10 sensing nodes assuming full battery capacity. The algorithm was started, having available all sensor nodes of the grid at full battery capacities. The GA runs gave best result for 3000 generations. The Optimized parameters of best GA runs are as follows

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Table III Optimized Parameter Values for GA Network Layout

Design Parameter	**GA1**	**GA2**
FC	0.9	0.85
OpCcE	0	0
SORE	0	0
SpCc	21.5	20.75
NE	1.78	1.74
Nccn	4	4
Nn1	71	68
Nn2	14	20
Ninact	11	8

Fig 3 indicates Average Fitness function and the progress of best individual .It can be noted that the fitness function is decreased through the process of evolution. The Fig4 shows that the network energy parameter is optimized in the process of Evolution as per the requirement. It can be noted that during the initial process the variation is random but as the generations continues to evolve parameter is optimized. The evolution of overlaps per cache in charge error (OpCcE) parameter is shown in Fig 5 It is evident that the algorithm tries to minimize the error and is successful in making it to zero. In Fig 6 the sensor out of range error (SORE) is optimized in the process of evolution. The optimization aims at increasing two parameters sensor per cache in charge and field coverage .This is evident from Fig7 and Fig.8 that the sensor per cache in charge and Field coverage is increased. The sensor per cache in charge is increased to 21 and the field coverage is increased to 90 %.

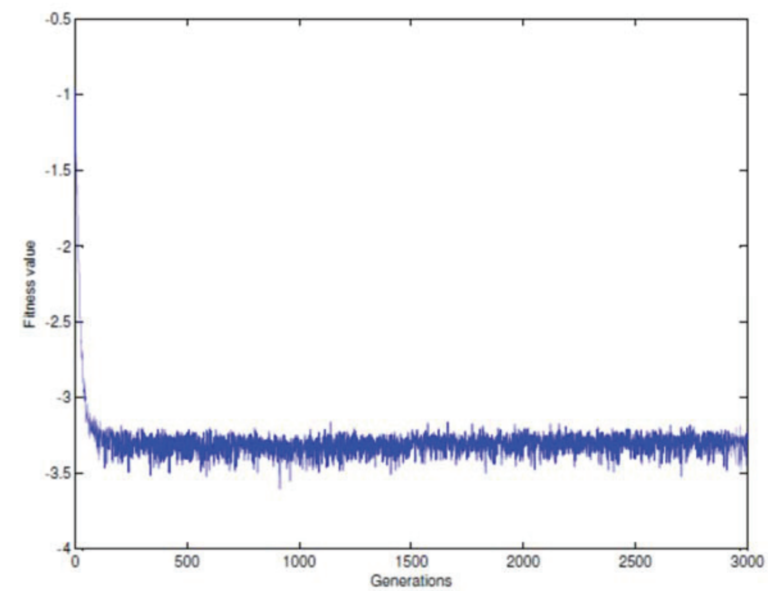

Figure.3- Fitness function

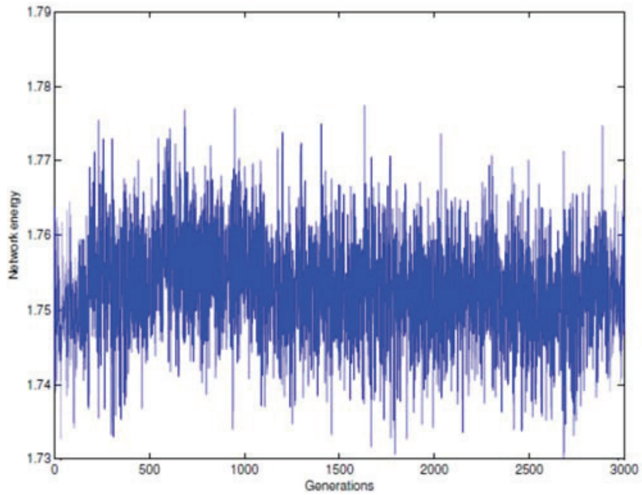

Figure.4- Optimization of Network Energy

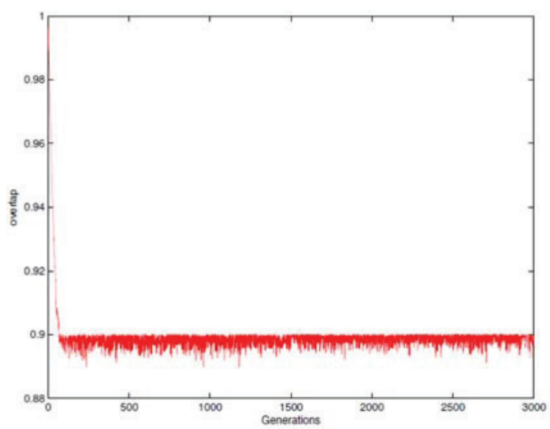

Figure.5- Optimization of OPCcE

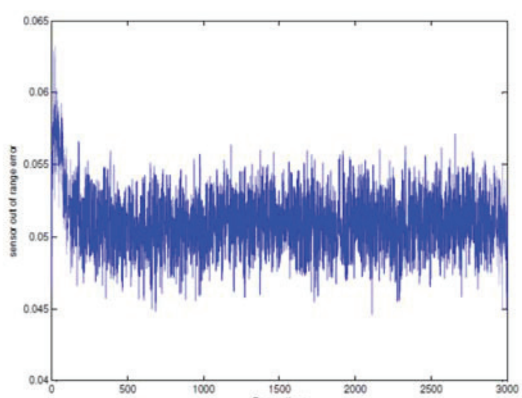

Figure.6- Optimization of SORE

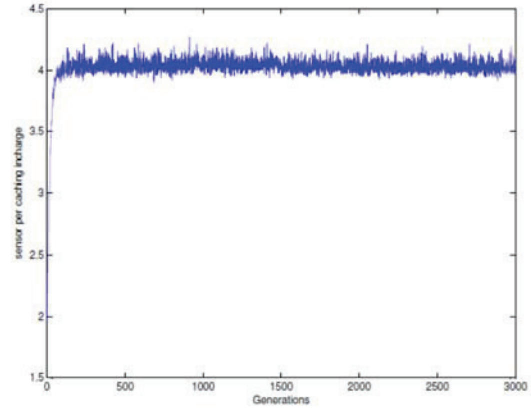

Figure.7- Optimization of SPCc

The optimized through several GA runs obtained is placed in NS-2 and the cooperative Caching is run. In this network the nodes within one CCN forms a community.

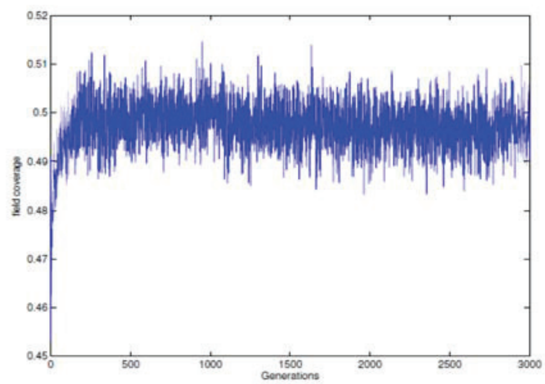

Figure.8- Optimization of Field coverage

VI Conclusion

The use of genetic algorithm based cache node placement methodology for a wireless sensor network. A fixed wireless network of sensors of different operating modes was considered on a grid deployment and the GA system decided which sensor should be active, which ones should operate as community caching node and whether each of remaining active nodes should have high or low transmission range. The network layout design was optimized by taking into consideration application specific parameter, connectivity parameters and energy related parameters. From the evolution of network characteristics during the optimization process, we can conclude that it is preferable to operate a relatively high number of sensors and achieve lower energy consumption for communication purposes than having less active sensors with consequently larger energy consumption for communication purposes.

VII References

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